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SECTION 3 - PAVEMENT DESIGN

3.1.0 GENERAL

The City has observed premature distress on many of the heavily traveled streets and on streets built on subgrade soils with high plasticity indices (P.I. >20). In response to this problem the City has upgraded its construction requirements.

The computer program developed by the City of Austin was adapted from the Texas Department of Transportation (TxDOT) design system currently being utilized by TxDOT and its local districts and is modified for municipal applications. The TxDOT design system was adapted from the American Association of State Highways and Transportation Officials (AASHTO), Interim Design Method, with modifications for local conditions and needs.

Modifications to the TxDOT highway programs were by the undertaken by the City of Austin to make the highway programs for rural highway design more suitable for municipal conditions. These improvements included the addition of: (1) curb and gutter costs; (2) subgrade excavation costs; (3) additional costs associated with future overlays including thickened edge, edge milling and overlay tapering; (4) the effects of the distribution of heavy trucks on city streets of different classification; and (5) revising the traffic modeling.

It is important to note that the City of Austin program may not produce appropriate critical stresses in flexible pavements designed for relatively low Average Daily Traffic (ADT) values. In order to insure adequate pavement designs for this situation, TxDOT Test Method Tex-117-E,"Triaxial Compression Tests for Disturbed Soils and Base Materials" should be used for comparison.

The minimum pavement thickness requirements are presented in Section 3.2.1 of this Manual.

The City has established a goal of at least a 20-year life cycle for the design of the City streets.

Whenever a soil investigation indicates that more than two (2) feet of expansive subgrade soil with P.I. greater than twenty (20) exists underneath the expected base layer one of the following measures shall be adopted:

1. Lime stabilize at least eight (8) inches of subgrade.
2. Other as may be approved by the Director of the Transportation Services Department or designated representative.

For additional information, see Figures 3-4 through 3-9 in Section 3.3.0 of this manual.

3.2.0 GENERAL CRITERIA

All streets shall be constructed on a compacted or stabilized subgrade, and shall consist of a base layer and Hot Mix Asphaltic Concrete (HMAC) surface layer, and/or a Portland Cement Concrete (PCC) pavement as designed by a Licensed

Geotechnical Engineer registered in the State of Texas, using:

1. The State Department of Highways and Public Transportation Triaxial Design Criteria; or,
2. The AASHTO Pavement Design Guide; and
3. The current edition of the City of Austin Municipal Flexible Pavement System.

The material selection shall consist of one or more of the following support layers that conform to the current edition of the City's DACS - Standard Specifications Manual.

1. Improved subgrade;
2. Compacted subbase, stabilized subbase;
3. Flexible base, asphalt stabilized base; and
4. A surface layer consisting of either HMAC or PCC.

For additional information, see Figures 3-4 through 3-9 in Section 3.3.0 of this Manual.

Soils Investigation

A subdivider shall, at his own expense, cause to be made a soils investigation by a qualified and independent geotechnical engineer licensed to practice in the State of Texas. The field investigation shall include test borings within the rights-of-way of all proposed streets. The number of locations of such borings shall be subject to the approval of the City Engineer. Atterberg limits and moisture contents shall be determined for all significant boring samples. The method used for these determinations shall be the same as those used by the State Department of Highways and Public Transportation using their latest Manual of Testing Procedures, 100-E Series test methods. The results of the soils investigation shall be presented to the subdivider and to the City Engineer in written report form. Included as a part of the report shall be a graphical or tabular presentation of the boring data giving Atterberg limits and moisture contents, a soil description of the layers of different soils encountered in the profile of the hole, their limits in relation to a fixed surface datum, and such other information as needed to complete the soils investigation for pavement design purposes. Minimum depth of soil profile boring holes shall be ten (10) feet unless solid rock formations are encountered sooner.

A written report containing pavement design data and recommendations based on the soils investigation shall be prepared at the subdivider's expense by a qualified geotechnical engineer licensed to practice in the State of Texas and shall be presented to the subdivider and to the City Engineer. The report shall state the load criteria and the soil classifications used. When approved by the City Engineer, the geotechnical engineer preparing the report may use the triaxial classification soils data given in SDHPT report number 3-05-71-035, entitled "Triaxial Classification of the Surface Soils of Texas as Grouped by Soil Conservation Service Series."

When using the triaxial data, the report shall so state. The pavement design shall be subject to the approval of the City Engineer and shall be shown on the street construction plans as approved. Where the plasticity index of the subgrade soil (on which the street is to be built) is in excess of twenty (20), the pavement design shall include subgrade stabilization unless approved otherwise by the City Engineer. When subgrade soils are stabilized the minimum depth of stabilization shall by eight (8) inches unless otherwise approved by the City Engineer. In swelling clay soils stabilization, the stabilizer used shall be by addition of lime. The lime shall be applied to the subgrade soil in slurry form unless otherwise approved by the City Engineer.

3.2.1 MINIMUM HMAC PAVEMENT REQUIREMENTS

A. LOCAL RESIDENTIAL STREETS:

1. Minimum Street Section Design Requirements:
    a. Total Equivalent 18 Kip Single Axle Load Application = 42,000
    b. ADT < 2000 vehicles
    c. Trucks = 3%
    d. Growth Factor = 3%
    e. LFDF = 0.75
    f. Wheel load = 8 kips

2. Materials used shall be as follows:

a. HMAC Surface Course shall be Type “D” as defined by City of Round Rock DACS - Standard Specifications Manual, Item 340.

b. PRIME COAT shall be Type “MC-30” as defined by City of Round Rock DACS - Standard Specifications Manual, Item 301.

c. FLEXIBLE BASE shall be as defined by City of Round Rock DACS - Standard Specifications Manual, Item 210.

d. STABILIZED SUBGRADE shall be with Type “B” Lime Slurry meeting the requirements of City of Round Rock DACS - Standard Specifications Manual, Item 202.

e. SUBBASE shall be Type “A”, Grade “2” as defined by TxDOT Standard Specifications for Construction of Highways, Streets and Bridges (1993), Division II, Item 247.

3. Minimum Pavement Structural Section where the PI < 20:
    a. HMAC = 1 ½”
    b. PRIME COAT
    c. FLEXIBLE BASE = 8”

d. SUBBASE as required

4. Minimum Pavement Structural Section where the 20 < PI < 35:
   a. HMAC = 1 ½"
   b. PRIME COAT
   c. FLEXIBLE BASE = 10" and STABILIZED SUBGRADE = 8"

5. Minimum Pavement Structural Section where the 35 < PI < 45:
   a. HMAC = 1 ½"
   b. PRIME COAT
   c. FLEXIBLE BASE = 10" and STABILIZED SUBGRADE = 10"

6. Minimum Street Section where the PI > 45:
   a. Design by a Certified Geotechnical Engineer is required.
   b. The pavement structural section shall, in no case, be less than the requirements shown in 5 above.

B. <u>LOCAL NON-RESIDENTIAL STREETS:</u>

1. Minimum Street Section Design Requirements:
   a. Total Equivalent 18 Kip Single Axle Load Application = 120,000
   b. ADT < 2000 vehicles
   c. Trucks = 10%
   d. Growth Factor = 1.5%
   e. LFDF = 0.90
   f. Wheel load = 8 kips

2. Materials used shall be as follows:

   a. HMAC Surface Course shall be Type "C" as defined by <u>City of Round Rock DACS - Standard Specifications Manual</u>, Item 340.

   b. PRIME COAT shall be Type-Grade "MC-30" as defined by <u>City of Round Rock DACS - Standard Specifications Manual</u>, Item 301.

   c. FLEXIBLE BASE shall be as defined by <u>City of Round Rock DACS - Standard Specifications Manual</u>, Item 247.

   d. LIME STABILIZED SUBGRADE shall be Type "A" Hydrated Lime meeting the requirements of <u>City of Round Rock DACS - Standard Specifications Manual</u>, Item 247.

   e. SELECT SUBBASE shall be Type "A", Grade "2" as defined by City of Round Rock DACS - Standard Specifications Manual, Item 260 & 264

3. Minimum Pavement Structural Section where the PI < 20:
   a. HMAC = 2”
   b. PRIME COAT
   c. FLEXIBLE BASE = 12”
   d. SUBBASE as required

4. Minimum Pavement Structural Section where the 20 <PI < 35:
   a. HMAC = 2”
   b. PRIME COAT
   c. FLEXIBLE BASE = 12” and STABILIZED SUBGRADE = 10”

5. Minimum Pavement Structural Section where the 35 < PI < 45:
   a. HMAC = 2”
   b. PRIME COAT
   c. FLEXIBLE BASE = 14” and STABILIZED SUBGRADE = 12”

6. Minimum Pavement Structural Section where the PI > 45:
   a. Design by a Certified Geotechnical Engineer is required.
   b. The pavement structural section shall, in no case, be less than the requirements shown in 5 above.

C. LOCAL RURAL STREETS

1. Minimum Structural Pavement Section Design Requirements:
   a. Total Equivalent 18 Kip Single Axle Load Application = 25,000
   b. ADT < 2000 vehicles
   c. Trucks = 2%
   d. Growth Factor = 1.5%
   e. LFDF = 0.70
   f. Wheel load = 6 kips

2. Materials used shall be as follows:
   a. HMAC Surface Course shall be Type “C” as defined by City of Round Rock DACS - Standard Specifications Manual, Item 340.

   b. PRIME COAT shall be Type-Grade “MC-30” as defined by City of Round Rock DACS - Standard Specifications Manual, Item 301.

   c. FLEXIBLE BASE shall be as defined by City of Round Rock DACS - Standard Specifications Manual, Item 210.

d. STABILIZED SUBGRADE shall be with Type “B” Lime Slurry meeting the requirements of City of Round Rock DACS - Standard Specifications Manual, Item 202.

e. SUBBASE shall be Type “A”, Grade “2” as defined by TxDOT – Standard Specifications for Construction of Highways, Streets and Bridges (1993), Division II, Item 247.

3. Minimum Structural Pavement Section where the PI < 20:
   a. HMAC = 2”
   b. PRIME COAT
   c. FLEXIBLE BASE = 8”
   d. SUBBASE as required

4. Minimum Structural Pavement Section where the 20 < PI < 35:
   a. HMAC = 2”
   b. PRIME COAT
   c. FLEXIBLE BASE = 8” and STABILIZED SUBGRADE = 8”

5. Minimum Structural Pavement Section where the 35 < PI < 45:
   a. HMAC = 2”
   b. PRIME COAT
   c. FLEXIBLE BASE = 12” and STABILIZED SUBGRADE = 8”

6. Minimum Street Section where the PI > 45:
   a. Design by a Certified Geotechnical Engineer is required.
   b. The pavement structural section shall, in no case, be less than the requirements shown in 5 above.

Exception to the flexible base course: thickness may be reduced by one (1) inch when the material is placed on solid rock.

D. LOCAL COLLECTOR STREETS:

1. Minimum Street Section Design Requirements:
   a. Total Equivalent 18 Kip Single Axle Load Application = 150,000
   b. ADT = 2000 – 4000 vehicles
   c. Trucks = 3%
   d. Growth Factor = 3.5%
   e. LFDF = 0.90
   f. Wheel load = 8 kips

2. Materials used shall be as follows:

a. HMAC Surface Course shall be Type “C” as defined by <u>City of Round Rock DACS - Standard Specifications Manual</u>, Item 340.

b. PRIME COAT shall be Type-Grade “MC-30” as defined by <u>City of Round Rock DACS - Standard Specifications Manual</u>, Item 301.

c. FLEXIBLE BASE shall be as defined by <u>City of Round Rock DACS - Standard Specifications Manual</u>, Item 210.

d. STABILIZED SUBGRADE shall be with Type “B” Lime Slurry meeting the requirements of <u>City of Round Rock DACS - Standard Specifications Manual</u>, Item 202.

e. SUBBASE shall be Type “A”, Grade “2” as defined by <u>TxDOT – Standard Specifications for Construction of Highways, Streets, and Bridges (1993)</u>, Division II, Item 247.

3. Minimum Pavement Structural Section where the PI < 20:

a. HMAC = 2”
b. PRIME COAT
c. FLEXIBLE BASE = 10”
d. SUBBASE as required

4. Minimum Pavement Structural Section where the 20 < PI < 35:
a. HMAC = 2”
b. PRIME COAT
c. FLEXIBLE BASE = 12” and STABILIZED SUBGRADE = 8”

5. Minimum Pavement Structural Section where the 35 < PI < 45:
a. HMAC = 2”
b. PRIME COAT
c. FLEXIBLE BASE = 12” and STABILIZED SUBGRADE = 10”

6. Minimum Pavement Structural Section where the PI > 45:
a. Design by a Certified Geotechnical Engineer Design required.
b. The pavement structural section shall, in no case, be less than the requirements shown in 5 above.

E. <u>MAJOR COLLECTOR STREETS</u>

1. Minimum Structural Pavement Section Design Requirements:
a. Total Equivalent 18 Kip Single Axle Load Application = 700,000

b. ADT = 4000 – 6000 vehicles
c. Trucks = 10%
d. Growth Factor = 4%
e. LFDF = 1.1
f. Wheel load = 11 kips

2. Materials used shall be as follows:

   a. HMAC Surface Course shall be Type “C” as defined by City of Round Rock DACS - Standard Specifications Manual, Item 340.

   b. PRIME COAT shall be Type-Grade “MC-30” as defined by City of Round Rock DACS - Standard Specifications Manual, Item 301.

   c. FLEXIBLE BASE shall be as defined by City of Round Rock DACS - Standard Specifications Manual, Item 210.

   d. STABILIZED SUBGRADE shall be with Type “A” Lime Slurry meeting the requirements of City of Round Rock DACS - Standard Specifications Manual, Item 202.

   e. SUBBASE shall be Type “A”, Grade “2” as defined by TxDOT – Standard Specifications for Construction of Highways, Streets, and Bridges (1993), Division II, Item 247.

3. Minimum Structural Pavement Section where the PI < 20:
   a. HMAC = 3”
   b. PRIME COAT
   c. FLEXIBLE BASE = 14”
   d. SUBBASE as required

4. Minimum Structural Pavement Section where the 20 <PI < 35:
   a. HMAC = 3”
   b. PRIME COAT
   c. FLEXIBLE BASE = 12” and STABILIZED SUBGRADE = 8”

5. Minimum Structural Pavement Section where the 35 < PI < 45:
   a. HMAC = 3”
   b. PRIME COAT
   c. FLEXIBLE BASE = 15” and STABILIZED SUBGRADE = 10”

6. Design Required Minimum Street Section where the PI > 45:
   a. Design by a Certified Geotechnical Engineer is required.

b. The pavement structural section shall, in no case, be less than the requirements shown in 5 above.

F. COMMERCIAL / INDUSTRIAL COLLECTOR STREETS (LOCAL OR MAJOR)

1. Minimum Structural Pavement Section Design Requirements:
   a. Total Equivalent 18 Kip Single Axle Load Application = 2,500,000
   b. ADT > 6000 vehicles
   c. Trucks = 10%
   d. Growth Factor = 3%
   e. LFDF = 1.15
   f. Wheel load = 14 kips

2. Materials used shall be as follows:
   a. HMAC Surface Course shall be Type “C” as defined by City of Round Rock DACS - Standard Specifications Manual, Item 340.

   b. PRIME COAT shall be Type-Grade “MC-30” as defined by City of Round Rock DACS - Standard Specifications Manual, Item 301.

   c. FLEXIBLE BASE shall be as defined by City of Round Rock DACS - Standard Specifications Manual, Item 210.

   d. LIME STABILIZED SUBGRADE shall be with Type “B” Lime Slurry meeting the requirements of City of Round Rock DACS - Standard Specifications Manual, Item 202.

   e. SUBBASE shall be Type “A”, Grade “2” as defined by TxDOT – Standard Specifications for Construction of Highways, Streets, and Bridges (1993), Division II, Item 247.

3. Minimum Structural Pavement Section where the PI < 20:
   a. HMAC = 4”
   b. PRIME COAT
   c. FLEXIBLE BASE = 18”
   d. SUBBASE as required

4. Minimum Structural Pavement Section where the 20 < PI < 35:
   a. HMAC = 4”
   b. PRIME COAT
   c. FLEXIBLE BASE = 16” and STABILIZED SUBGRADE = 8”

5. Minimum Structural Pavement Section where the 35 < PI < 45:
   a. HMAC = 5”
   b. PRIME COAT

c. FLEXIBLE BASE = 16” and STABILIZED SUBGRADE = 10”

6. Minimum Structural Pavement Section where the PI > 45:
   a. Design by a Certified Geotechnical Engineer required.
   b. The pavement structural section shall, in no case, be less than the requirements shown in 5 above.

G. MINOR ARTERIAL STREETS:

1. Minimum Structural Pavement Section Design Requirements:
   a. Total Equivalent 18 Kip Single Axle Load Application = 2,500,000
   b. ADT = 8000 – 12000 vehicles
   c. Trucks = 10%
   d. Growth Factor = 5%
   e. LFDF = 1.15
   f. Wheel load = 14 kips

2. Materials used shall be as follows:
   a. HMAC Surface Course shall be Type “C” as defined by City of Round Rock DACS - Standard Specifications Manual, Item 340.

   b. PRIME COAT shall be Type-Grade “MC-30” as defined by City of Round Rock DACS - Standard Specifications Manual, Item 301.

   c. FLEXIBLE BASE shall be as defined by City of Round Rock DACS - Standard Specifications Manual, Item 210.

   d. STABILIZED SUBGRADE shall be with Type “B” Lime Slurry meeting the requirements of City of Round Rock DACS - Standard Specifications Manual, Item 202.

   e. SUBBASE shall be Type “A”, Grade “2” as defined by TxDOT – Standard Specifications for Construction of Highways, Streets, and Bridges (1993), Division II, Item 247.

3. Minimum Structural Pavement Section where the PI < 20:
   a. HMAC = 4”
   b. PRIME COAT
   c. FLEXIBLE BASE = 18”
   d. SUBBASE as required

4. Minimum Structural Pavement Section where the 20 < PI < 35:
   a. HMAC = 4”
   b. PRIME COAT
   c. FLEXIBLE BASE = 16” and SUBBASE = 10” OR
      FLEXIBLE BASE = 16” and STABILIZED SUBBASE = 8”

5. Minimum Street Section where the 35 < PI < 45:
    a. HMAC =5”
    b. PRIME COAT
    c. FLEXIBLE BASE = 16” and SUBBASE = 12” OR
       FLEXIBLE BASE = 16” and STABILIZED SUBBASE = 10”

6. Minimum Structural Pavement Section where the PI > 45:
    a. Design by a Certified Geotechnical Engineer is required.
    b. The pavement structural section shall be less than the requirements shown in 5 above.

H. <u>MAJOR ARTERIAL STREETS:</u>

1. Minimum Street Section Design Requirements:
    a. Total Equivalent 18 Kip Single Axle Load Application = 8,000,000
    b. ADT > 12,000 vehicles
    c. Trucks = 10%
    d. Growth Factor = 5%
    e. LFDF = 1.15
    f. Wheel load = 14 kips

2. Materials used shall be as follows:
    a. HMAC Surface Course shall be Type “C” as defined by <u>City of Round Rock DACS - Standard Specifications Manual</u>, Item 340.

    b. PRIME COAT shall be Type-Grade “MC-30” as defined by <u>City of Round Rock DACS - Standard Specifications Manual</u>, Item 301.

    c. FLEXIBLE BASE shall be as defined by <u>City of Round Rock DACS - Standard Specifications Manual</u>, Item 210.

    d. STABILIZED SUBGRADE shall be with Type “B” Lime Slurry meeting the requirements of <u>City of Round Rock DACS - Standard Specifications Manual</u>, Item 202.

    e. SUBBASE shall be Type “A”, Grade “2” as defined by <u>TxDOT – Standard Specifications for Construction of Highways, Streets, and Bridges (1993)</u>, Division II, Item 247.

3. Minimum Structural Pavement Section where the PI < 20:
    a. HMAC = 6”
    b. PRIME COAT
    c. FLEXIBLE BASE = 18”

d. SUBBASE as required

4. Minimum Structural Pavement Section where the 20 < PI < 35:
   a. HMAC = 6”
   b. PRIME COAT
   c. FLEXIBLE BASE = 16” and SUBBASE = 12” OR
      FLEXIBLE BASE = 16” and STABILIZED SUBBASE = 10”

5. Minimum Structural Pavement Section where the 35 < PI < 45:
   a. HMAC = 6”
   b. PRIME COAT
   c. FLEXIBLE BASE = 22” and SUBBASE = 18” OR
      FLEXIBLE BASE = 22” and STABILIZED SUBBASE = 12”

6. Minimum Structural Pavement Section where the PI > 45:
   a. Design by a Certified Geotechnical Engineer is required.
   b. The pavement structural section shall, in no case, be less than the requirements shown in 5 above.

I. SECTION LIMITS

Where subgrade stabilization is provided, the stabilized subgrade and succeeding subbase and base courses shall extend a minimum of three (3) feet behind the back of curb. Where subgrade stabilization is not provided, subbase and base courses shall extend a minimum of eighteen (18) inches behind the back of curb.

3.2.2 Stabilization Selection and Mix Design for Subgrade and Base Materials

The stabilization selection and mix design approach shall include the selection of the type of stabilizer (see Figure 3-10, in Section 3.3.0 of this Manual) and the development of an appropriate stabilized mix design (see Figures 3-11 and 3-12, in Section 3.3.0 of this Manual) based upon the gradation (TxDOT Test Method Tex-110-E), plasticity index (TxDOT Test Method Tex-106-E) and pH (TxDOT Test Method Tex-128-E) of the candidate soil mixture.

Appropriate mix designs for any stabilized/treated subgrade, subbase and base layers shall be developed by a Registered Professional Engineer, licensed in the State of Texas.

A. Lime Stabilization

The principal goal of the mixture design process is the establishment of an appropriate lime content for construction. However, it should be noted that there may be instances where acceptable soil-lime mixtures may not be obtained regardless of the lime percentages used to treat the base and subbase materials. The flow diagram presented in Figure 3-10, in Section 3.3.0 of this Manual, shall be used as an aid in defining those soil mixtures that are expected to be amenable to lime treatment.

In general, the addition of lime to a fine-grained soils results in mixtures that display decreased plasticity, improved workability, reduced volume change characteristics and strength increases. Improvement in soil strength, however, does not always develop with the addition of lime. In general soils classified by the AASHTO method as A-4, A-5, A-6, A-7 and sometimes A-2-7 and A-2-6 are more readily susceptible to stabilization with lime. It should be noted that a number of variables, including soil type, lime type, lime percentage and curing conditions can impact the properties of soil-lime mixtures.

The impact of lime on the post-conditioned properties of materials proposed for lime treatment can range from reduction in the plasticity properties (with minimal strength increases) to significant strength increases. The latter impact (i.e. significant strength increase) is identified as stabilization of lime-reactive soils/materials (i.e. normally soils/materials with pH values greater than seven (7), while the former impact (i.e. reduction in plasticity properties) is identified as conditioning of non-lime-reactive soils/materials (i.e. normally soils/materials with pH values less than seven (7). The type of lime treatment proposed for the work should be indicated in the mix design report (i.e. lime stabilization for strength increase or lime conditioning for plasticity reduction).

Most fine-grained soils can generally be conditioned / stabilized effectively with three (3) to ten (10) percent of lime addition (dry weight of soil basis). The lower percent lime additions are normally identified with lime conditioning (with minimal strength increases) of the soil material, while the higher percent lime additions are normally necessary to achieve lime soil mixtures with significant strength increases.

In the case of lime conditioning of soil mixtures (with minimal strength increases), the lime conditioned soil mixture design for the City of Round Rock shall be developed using TxDOT Test Method Tex-112-E, “Method of Admixing Lime to Reduce Plasticity Index of Soils”.

In development of a lime stabilized soil mix design for the City of Round Rock, the mix design approach presented in Figure 3-11, in Section 3.3.0. of this Manual and the procedures specified in TxDOT Test Method Tex-121-E, “Soil-Lime Testing”, shall be used to establish the lime content that would produce a twenty-eight (28) day unconfined compressive strength (TxDOT Test Method Tex-117-E) of fifty (50) psi for a lime stabilized subgrade and one hundred (100) psi for a lime stabilized base layer.

The minimum rate of lime solids application shall be five (5) percent by weight (mass) for non-lime-reactive materials (pH of 7.0 or less) or seven (7) percent by weight (mass) for lime-reactive materials (pH greater than 7.0), unless indicated otherwise in the mix design process or as directed by the Engineer or designated representative.

B. Cement Stabilization

A wide range of soil types may be stabilized using Portland cement. The greatest effectiveness is with sands, sandy and silty soils, and clayey soils of low to medium plasticity. However, Portland cement is difficult to mix into soils with a plasticity index that exceeds thirty (30). The flow diagram presented in Figure 3-12, in Section 3.3.0 of this Manual shall be used as an aid in defining those soil mixtures that are expected to be amenable to cement treatment.

Soils mixtures that are acid, neutral or alkaline may well respond to cement treatment; however the higher pH soils react more favorably to cement addition and undergo significant strength increases. Although some organic matter such as un-decomposed vegetation may not influence stabilization adversely, other organic compounds of lower molecular weight, such as nucleic acid and dextrose, act as hydration retarders and reduce strength.

A special pH test (see Table 3-1) shall be used to provide an indication of the impact of organics on normal hardening of the cement stabilized soil mixture. In essence a 10:1 mixture (by weight) of soil and cement is mixed with distilled water for a minimum of fifteen (15) minutes and the pH of the combined mixture is then measured. If the pH value is at least 12.1, then it is probable that organic matter, if present, will not interfere with normal hydration/hardening of a soil-cement mixture. This pH measurement is a principal feature in identifying the soil mixtures that can likely be stabilized with cement and are candidates for development of a cement-soil mix design (see the mix design flow diagram presented in Figure 3-12, in Section 3.3.0 of this Manual).

Since sulfate attack is known to adversely affect some cement stabilized soil, the sulfate content of a soil should be considered in the selection of cement as a stabilizer. The impact of the sulfate factor on the mix design is also identified in Figure 3-12, in Section 3.3.0 of this Manual, where cement stabilization of soils with sulfate contents greater than 0.9 percent is discouraged. Procedures for determining sulfate content of soils are presented in Table 3-4 and 3-5.

There are additional selection criteria based on gradation and Atterberg limits test results that should be used in establishing the acceptability of a soil mixture for cement stabilization, specifically:

1. Fine-grained soils - Plasticity Index should be less than twenty (20) and the Liquid Limit less than forty (40);
2. Sandy soils - Plasticity Index should be less than thirty (30);
3. Coarse-grained (gravel) soils - minimum of forty (40) percent passing the no. 4 sieve; and
4. All soils - Plasticity Index should not exceed the number calculated in the following equation:

50 - percent passing no. 200 sieve

N = 20 + ------------------------------------
4

The properties of cement-treated soils are principally dependent on cement content, density, moisture content and confining pressure. It should also be noted that the addition of cement to a soil mixture could produce some change in both the optimum water content and maximum dry density for a given compactive effort. The principal goal of the cement stabilization mixture design process is therefore the establishment of an appropriate cement content-optimum moisture-density relationship appropriate for construction.

Most soils can generally be stabilized effectively with five (5) to sixteen (16) percent of cement addition (dry weight of soil basis). The lower percent cement additions are normally identified with coarser soil mixtures (AASHTO classifications A1 and A2), while the higher percent cement additions are normally necessary for the fine-grained soils (AASHTO A6 and A7). Estimates of cement requirements for various soil classifications are presented in Table 3-2 below.

In development of a cement stabilized soil mix design for the City, the mix design approach presented in Figure 3-12, in Section 3.3.0 of this Manual and the procedures specified in TxDOT Test Method Tex-120-E, “Soil-Cement Testing”, shall be used to establish the design cement content that would produce a mix that meets the allowable durability requirements presented in Table 3-3. The mix design report should include the molding moisture content, the dry density to the nearest 0.1 pcf, 7-day unconfined compressive strength to the nearest psi and the recommended cement content to the nearest whole percent.

The 7-day compressive strength associated with the recommended cement content should be used as the field control measure during construction. The 7-day compressive strength for cement stabilized soils can vary between one hundred (100) psi for fine-grained soils to more than a one thousand (1000) psi for coarse-grained soils.

If a mix design is not developed in the laboratory in accordance with in TxDOT Test Method Tex-120-E, “Soil-Cement Testing”, the minimum rate of cement solids application shall be the percent by weight for the specific soil classification (i.e. AASHTO or Unified Classification) identified with the percent cement for moisture-density testing (column 4 of Table 3-2), unless indicated otherwise by the Engineer or designated representative.

C. Lime-Cement Stabilization

Cement stabilization alone is normally not desired with high plasticity soil mixtures (i.e. soils with a plasticity Index greater than thirty (30) because of difficulties in the mixing phase. In this instance, combinations of lime and cement can often produce an acceptable combination. Lime is initially added to the soil mixture to increase the workability and mixing characteristics of the soil, as well as to reduce its plasticity. Cement is subsequently added to the lime–

soil mixture to provide rapid strength gain. The lime-cement combination stabilization of high plasticity soils is especially advantageous when rapid strength gain is required for placement during cooler weather conditions.

The lime content to reduce the plasticity index below thirty (30) should be established using TxDOT Test Method Tex-112-E, “Method of Admixing Lime to Reduce Plasticity Index of Soils”, while the TxDOT Test Method Tex-120-E, “Soil-Cement Testing”, shall be used to establish the design cement content that would produce a mix that meets the allowable durability requirements presented in Table 3-3.

The mix design report should include the molding moisture content, the dry density to the nearest 0.1 pcf, the 7-day unconfined compressive strength to the nearest psi and the recommended lime and cement contents to the nearest whole percent. Expected lime contents range from one (1) to three (3) percent, while the expected subsequent cement contents range from three (3) to ten (10) percent. The amount of lime and cement additions is dependent upon the type of soil.

The 7-day compressive strength associated with the recommended lime and cement contents should be used as the field control measure during construction.

Table 3-1 pH Test on Soil-cement Mixtures

Materials	pH meter (range of 14)
	150 ml plastic bottles with screw-top lids
	50 ml plastic beakers
	Distilled water
	Balance
	Oven
	Moisture cans
Procedures	1. Standardize pH meter with buffer solution with pH of 12.0
	2. Weigh 25.0 gms (to nearest .01 grams) of representative air dried soil sample that passes no. 40 sieve
	3. Transfer air-dried soil sample to 150 ml bottle with screw-top lids
	4. Add 2.5 grams of Portland cement to bottle
	5. Add distilled water to the bottle until a thick paste is created (Caution: too much water will effect the pH value)
	6. Stir the soil-cement and water until thoroughly blended
	7. After 15 minutes, transfer part of the paste to a plastic beaker and measure the pH.
	8. If pH is 12.1 or greater, the soil organic matter content should not interfere with cement stabilization

Table 3-2 Estimates of Cement Requirements for Various Soils

Soil Classification		% cement by weight (mass)	
AASHTO	**Unified**	**Usual range***	**Moisture-density**
A-1-a	GW, GP, GM, SW, SP, SM	3 to 5	5
A-1-b	GM, GP, SM, SP	5 to 8	6
A-2	GM, GC, SM, SC	5 to 9	7
A-3	SP	7 to 11	9
A-4	CL, ML	7 to 12	10
A-5	ML, MH, CH	8 to 13	10
A-6	CL, CH	9 to 15	12
A-7	OH, MH, CH	10 to 16	13

* Note: For most A horizon soils, the cement content should be increased four (4) percentage points if the soil is dark gray to gray and six (6) percentage points if the soil is black.

Table 3-3 Criteria Based on Wet-Dry and Freeze-Thaw Durability Tests

Soil Classification		Maximum allowable
AASHTO	**Unified**	**Weight Loss, %**
A-1-a	GW, GP, GM, SW, SP, SM	14
A-1-b	GM, GP, SM, SP	14
A-2	GM, GC, SM, SC	14*
A-3	SP	14
A-4	CL, ML	10
A-5	ML, MH, CH	10
A-6	CL, CH	7
A-7	OH, MH, CH	7

* Ten (10) percent is maximum allowable weight loss for A-2-6 and A-2-7

Table 3-4 Gravimetric Method for Determination of Sulfate in Soils

Reagents	Barium chloride: 10 % solution of $BaCl_2 2H_2O$. (Add 1 ml of 2% HCl to each 100 ml of solution to prevent formation of carbonate)
	Hydrochloric acid, 2 % solution (0.55N)s
	Magnesiun Chloride, 10% of $MgCl_2.6H_2O$
	Demineralized water
	Silver Nitrate, 0.1 N solution
Apparatus	Beaker, 1000 ml; Burner and ring stand; filtering flask, 500 ml
	Buchner funnel, 90 mm Filter paper, Whatman No. 40, 90 mm
	Filter paper, Whatman No. 42, 90 mm Saran wrap
	Crucible, ignition, or aluminum foil, heavy grade analytical balance
	Aspirator or other vacuum source
Procedures	1. Select a representative sample of air-dried soil and weigh approximately 10 gm. to the nearest 0.01 gm. Determine the moisture content of the air-dried soil. (Note: When sulfate content is expected to be less than 0.1 %, a sample weighing 20 gms. or more should be used)
	2. Boil the soil sample for 1 ½ hours in a beaker with mixture of 300 ml water and 15 ml HCl.
	3. Filter through Whatman No. 40 paper, wash with hot water, and dilute combined filtrate and washings to 50 mls.
	4. Take 100 ml of this solution and add $MgCl_2$ solution until no more precipitate is formed.
	5. Filter through Whatman No. 42 paper, wash with hot water, and dilute combined filtrate and washings to 200 mls.
	6. Heat 100 mls. Of this solution to boiling and add $BaCl_2$ solution very slowly until no more precipitate is formed. Continue boiling for about 5 minutes and let stand overnight in a warm place, covering the beaker with saran wrap.
	7. Filter through Whatman No. 42 paper, wash with hot water until free from chlorides (filtrate should show no precipitate when a drop of $AgNO_3$ solution is added).
	8. Dry filter paper in crucible or on sheet of aluminum foil. Ignite the paper. Weigh the residue on the analytical balance as $BaSO_4$.
Calculations	Percent SO_4 = ((Weight (mass) of residue) / (Oven-dry weight (mass) of initial sample)) x 411.6 Where Oven-dry weight (mass) of initial sample = ((Air-dry weight (mass) of initial sample) / (1 + (Air-dry moisture content (%) / 100%)
Note: If precipitated from a cold solution, barium sulfate is so finely dispersed that it cannot be retained when filtering by the above method. Precipitation from a warm, dilute solution will increase the crystal size. Due to the absorption (occlusion) of soluble salts during the precipitation by $BaSO_4$, a small error is introduced. This error can be minimized by permitting the precipitate to digest in a warm, dilute solution for a number of hours. This allows the more soluble small crystals of $BaSO_4$ to dissolve and recrystallize on the larger crystals.	

Table 3-5 Turbidimetric Method for Determination of Sulfate in Soils

Reagents	Barium chloride crystals (Grind analytical reagent grade barium chloride to pass a 1-mm sieve.)
	Ammonium acetate solution (0.5N) [Add dilute hydrochloric acid until the solution has a pH of 4.2.]; Distilled water
Apparatus	Moisture can; Oven; 200-ml beaker; Burner and ring stand; Filtering flask; Buchner funnel, 90 mm; Vacuum source
	Filter paper, Whatman No. 40, 90 mm; pH meter
	Spectrophotometer and standard tubes (Bausch and Lomb Spectronic 20 or equivalent)
Procedures	1. Select a representative sample of air-dried soil and weigh approximately 10 gm. to the nearest 0.01 gm. Determine the moisture content of the air-dried soil.
	2. Add the ammonium acetate solution to the soil sample. (the ratio of soil to solution should be approximately 1:5 by weight).
	3. Boil the soil sample for about 5 minutes.
	4. Filter through Whatman No. 40 paper. If the extracting solution is not clear, filter again.
	5. Take 10 ml of extracting solution (this may vary dependent upon the concentration of sulfate in the solution) and dilute with distilled water to about 40 ml. Add about 0.2 gm of barium chloride crystals and dilute to make the volume exactly equal to 50 ml. Stir for 1 minute.
	6. Immediately after the stirring period has ended, pour a portion of the solution into the standard tube and insert the tube into the cell of the spectrophotomer. Measure the turbidity at 30-second intervals for 4 minutes. Maximum turbidity is usually obtained within 2 minutes and the readings remain constant thereafter for 3 to 10 minutes. Consider the turbidity to be the maximum reading obtained in the 4-minute interval.
	7. Compare the turbidity reading with a standard curve and compute the sulfate concentration (as SO_4) in the original extracting solution. (The standard curve is secured by carrying out the procedure with standard potassium sulfate solutions.)
	8. Correction should be made for the apparent turbidity of the samples by running blanks in which no barium chloride is added.
Sample Calculations	Given: Weight of air-dried sample = 10.12 grams Moisture content = 9.36 % Weight of dry soil = 9.27 grams Total volume of extracting solution = 39.1 ml 10 ml of extracting solution was diluted to 50 ml after addition of barium chloride (see Step 5 above). The solution produces a transmission reading of 81. Dilution rate = 50 ml / 10 ml = 5 From the standard curve (developed as described below), a transmission reading of 81 corresponds to 16.0 ppm (see figure below) Concentration of original extracting solution = 16.0 x 5 = 80 ppm
	Percent SO_4 = (80.0 x 39.1 x 100) / (1000 x 1000 x 9.27) = 0.034 percent
Development of Standard Curve	1. Prepare sulfate solutions off 0, 4, 8, 12, 16, 20, 25, 30, 35, 40, 45, 50 ppm in separate test tubes. The sulfate solution is made from potassium sulfate salt dissolved in 0.5 N ammonium acetate (with pH adjusted to 4.2).
	2. Continue Steps 5 and 6 in the procedure, described previously.
	3. Draw the standard curve as shown below by plotting transmission readings for known concentrations of sulfate solutions.

3.3.0 FIGURES

Figure 3-1 Relationship between Flexural, Splitting Tensile and Compressive Strengths for Concrete made from Three Types of Aggregates

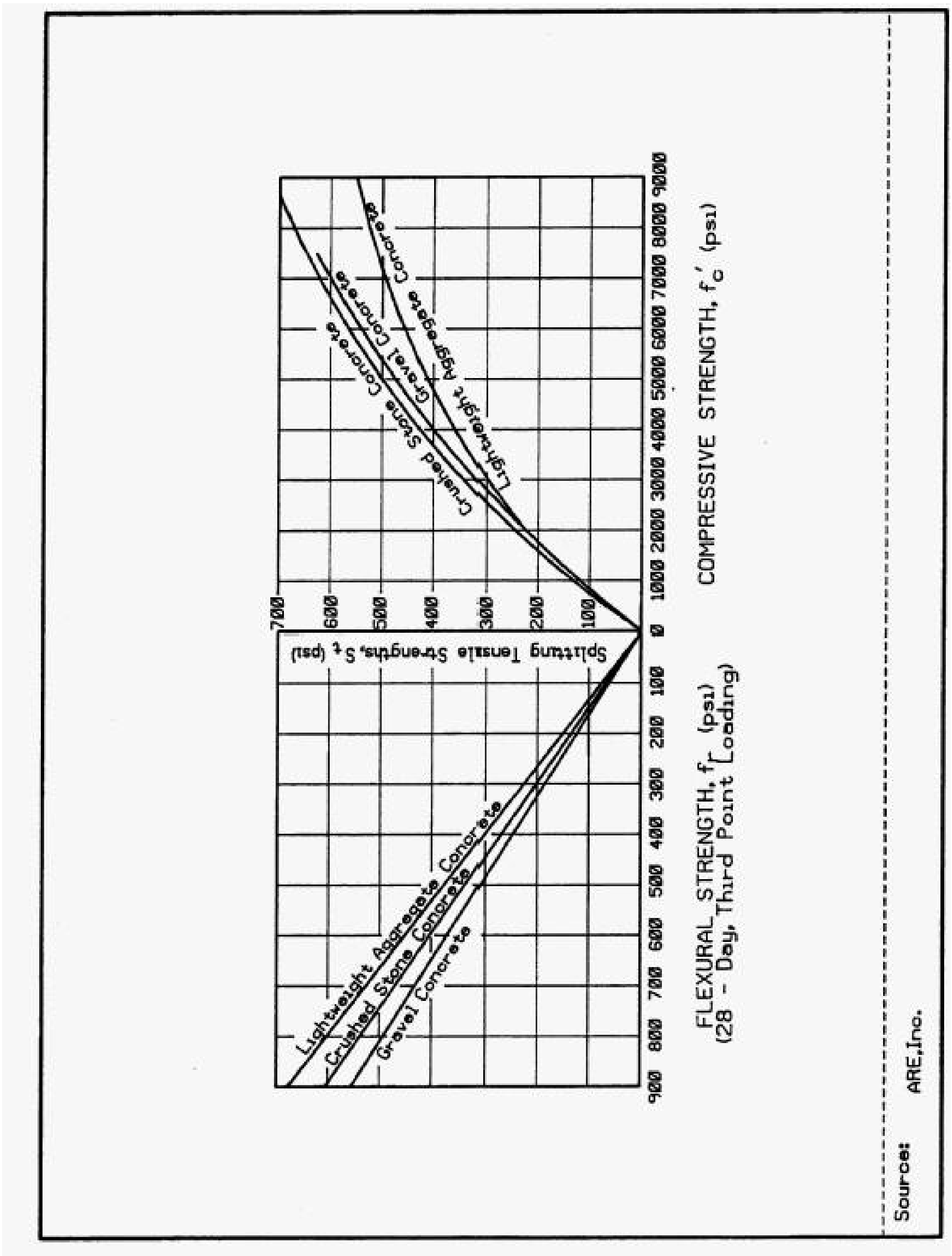


Figure 3-2 Determining Approximate Potential Vertical Rise (PVR) for Natural Soils

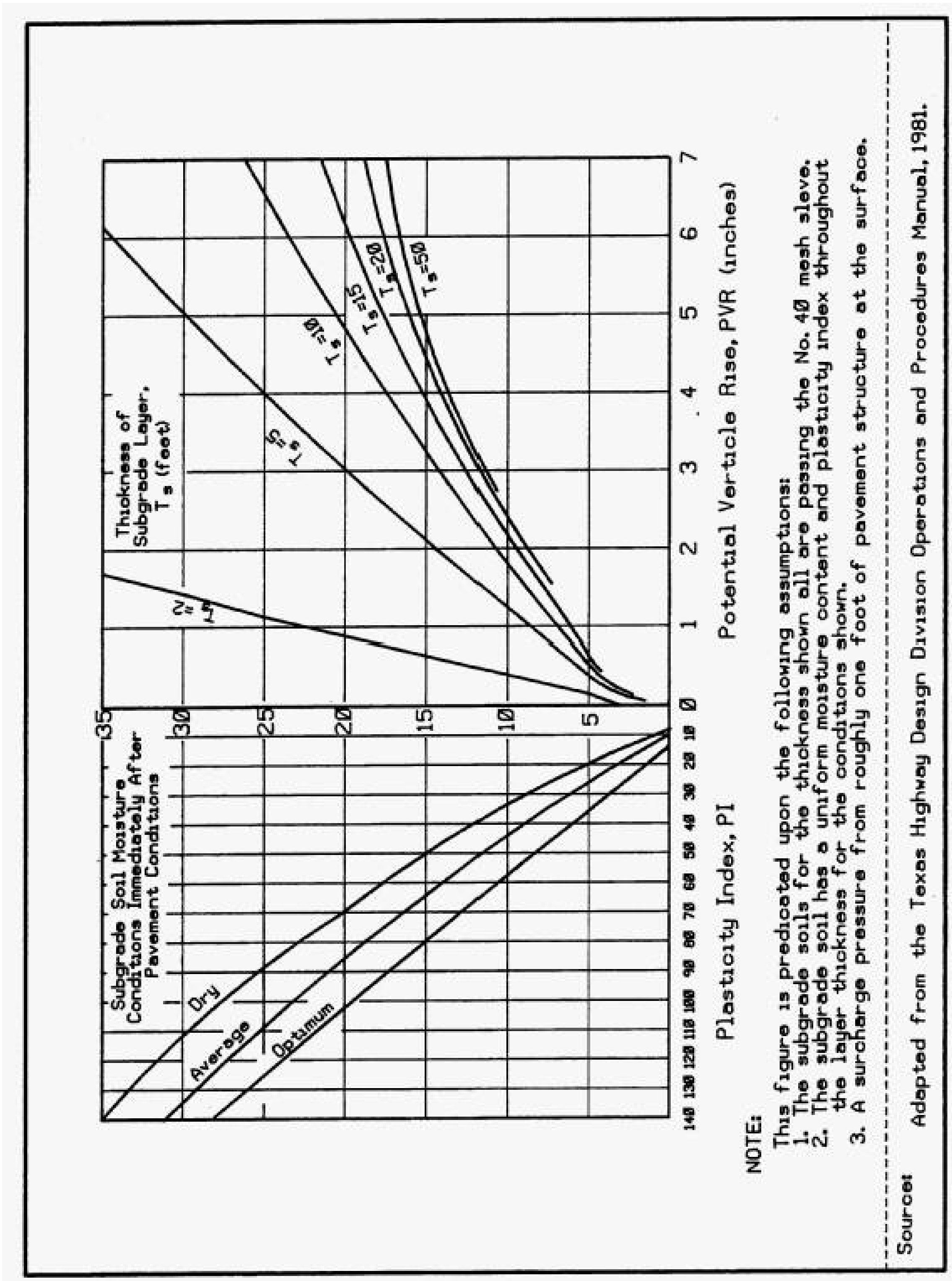
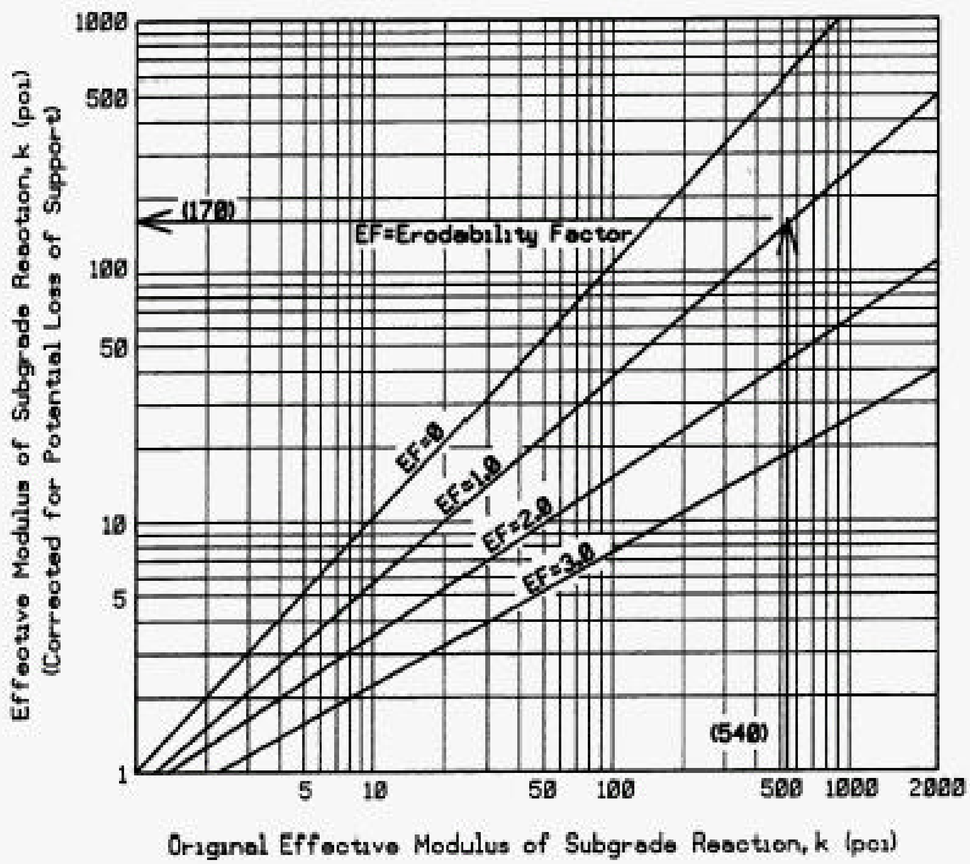
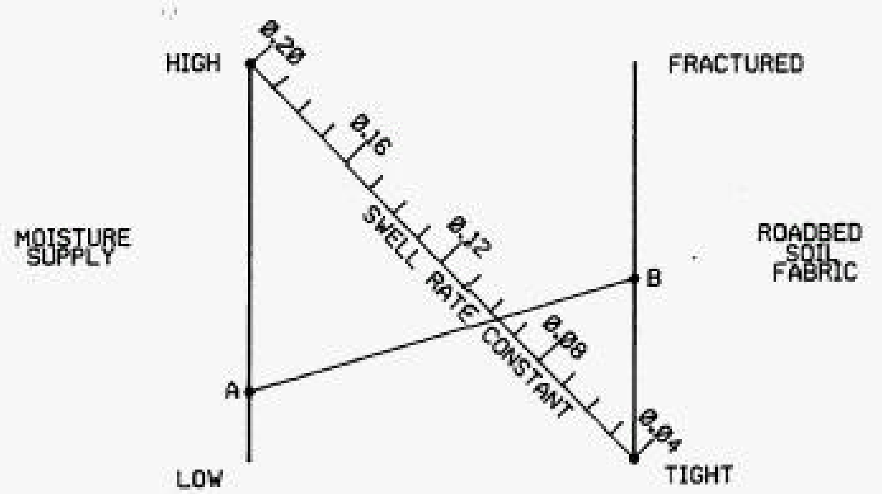


Figure 3-3 Correction of Effective Modulus of Subgrade Reaction for Potential Loss of Subbase Support



Source: Adapted from "A Systems Analysis of Rigid Pavement Design," Research Report 123-5, U.T. Center for Highway Research, 1971

Figure 3-4 Nomograph for Selecting Swelling Rate Constant



NOTES: a) LOW MOISTURE SUPPLY:

Low rainfall
Good drainage

b) HIGH MOISTURE SUPPLY

High rainfall
Poor drainage
Vicinity fo culverts, bridge abutments, inlet leads

c) SOIL FABRIC CONDITIONS (self explanatory)

d) USE OF THE NOMOGRAPH

1) Select the appropriate moisture supply condition which may be somewhere between low and high (such as A).
2) Select the appropriate soil fabric (such as B). This scale must be developed by each individual agency.
3) Draw a straight line between the selected points (A to B).
4) Read swell rate constant from the diagonal axis (read 0.10).

Source: Texas State Department of Highways and Public Transportation

Figure 3-5 Chart for Estimating Serviceability Loss Due Roadbed Swelling

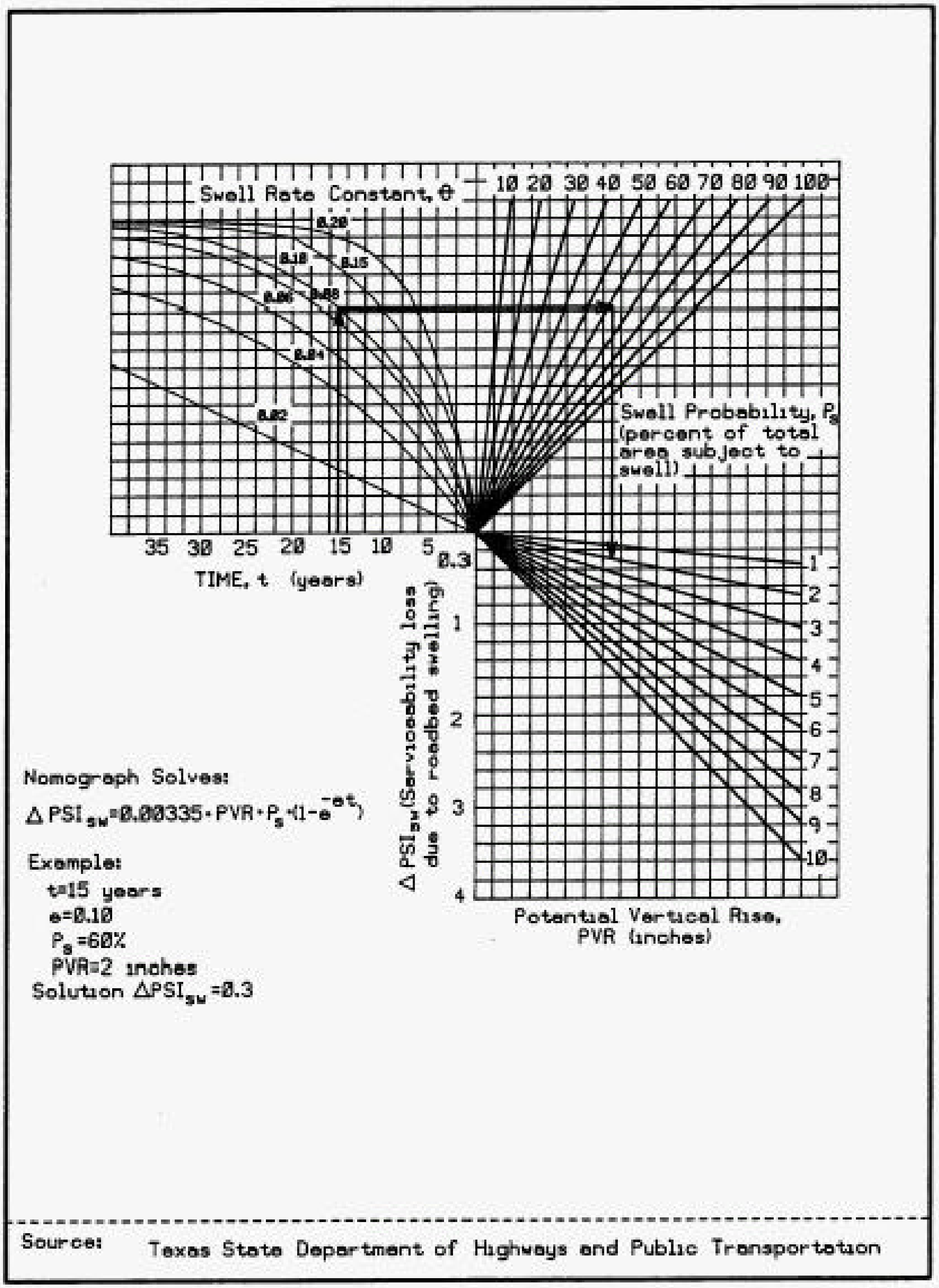


Figure 3-6 Approximate Method for Estimating Design Subgrade Stiffness Coefficient (SSC) from Laboratory Texas Triaxial Class for Subgrade

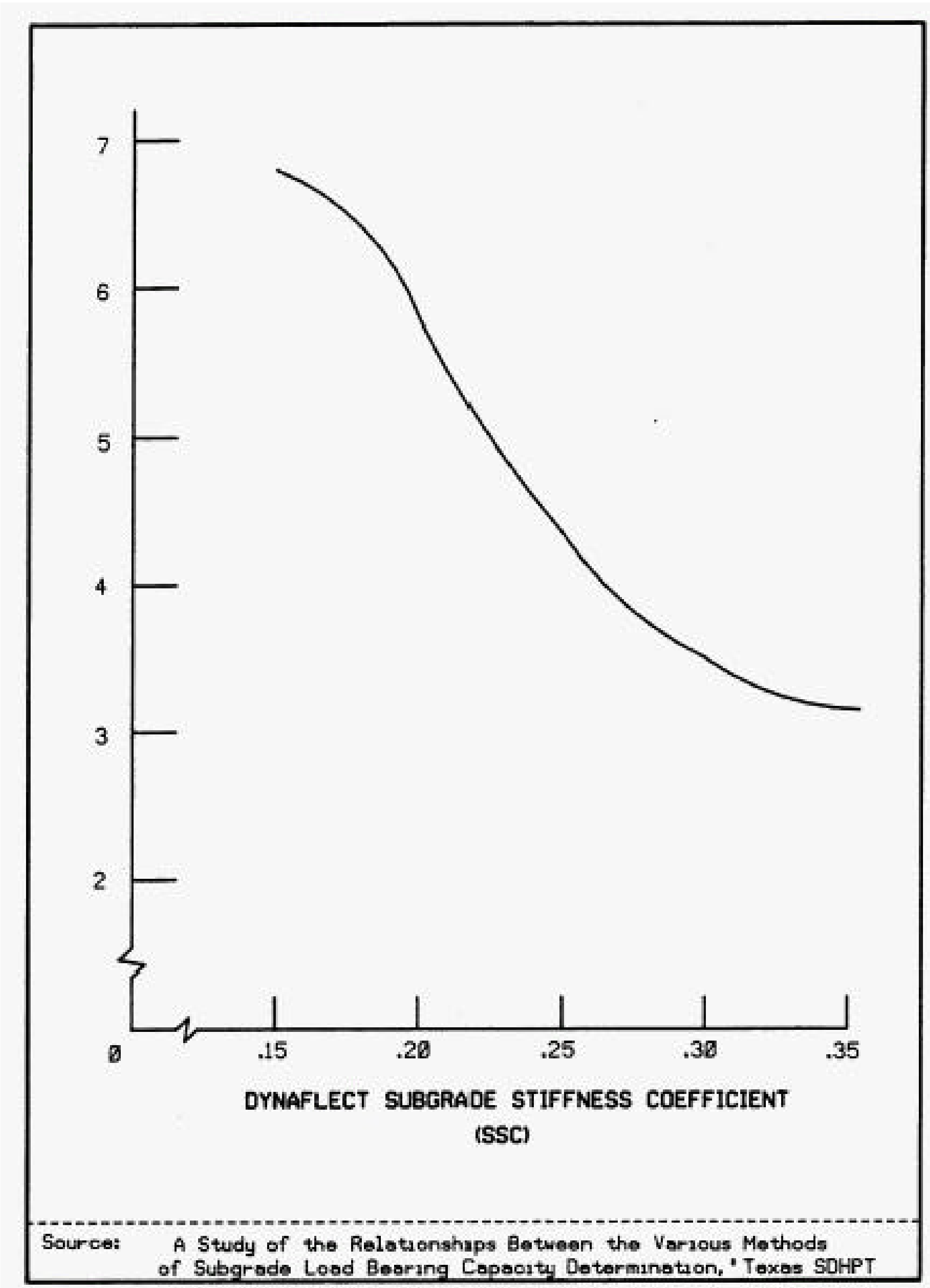
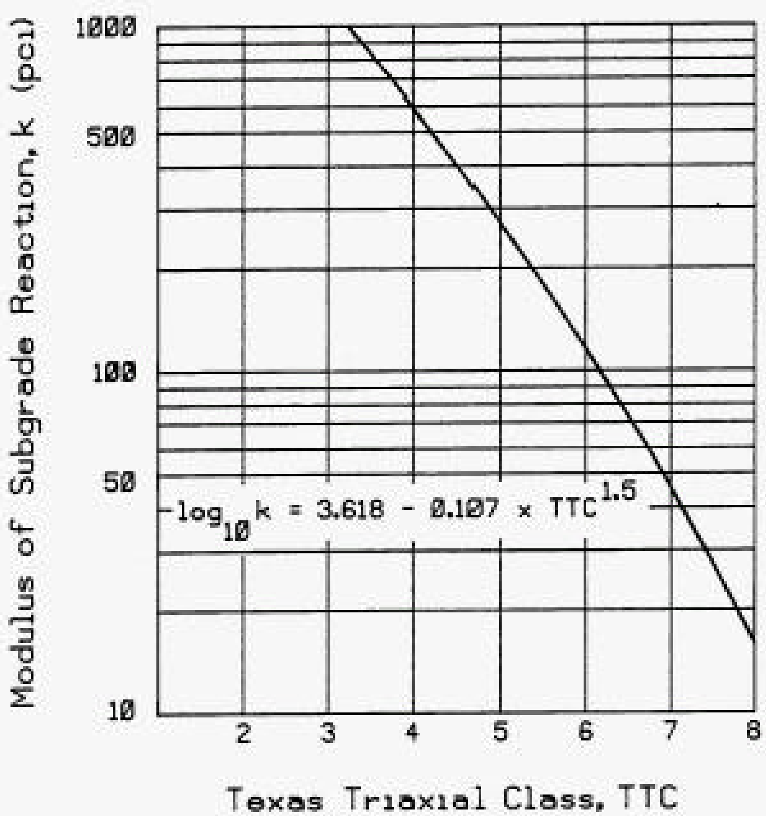


Figure 3-7 Recommended Relationship for Estimating Modulus of Subgrade Reaction from Triaxial Class



Source: Texas State Department of Highways and Public Transportation

Figure 3-8 Illustration of the Effect of Confidence Level on Design Pavement Structural Requirements

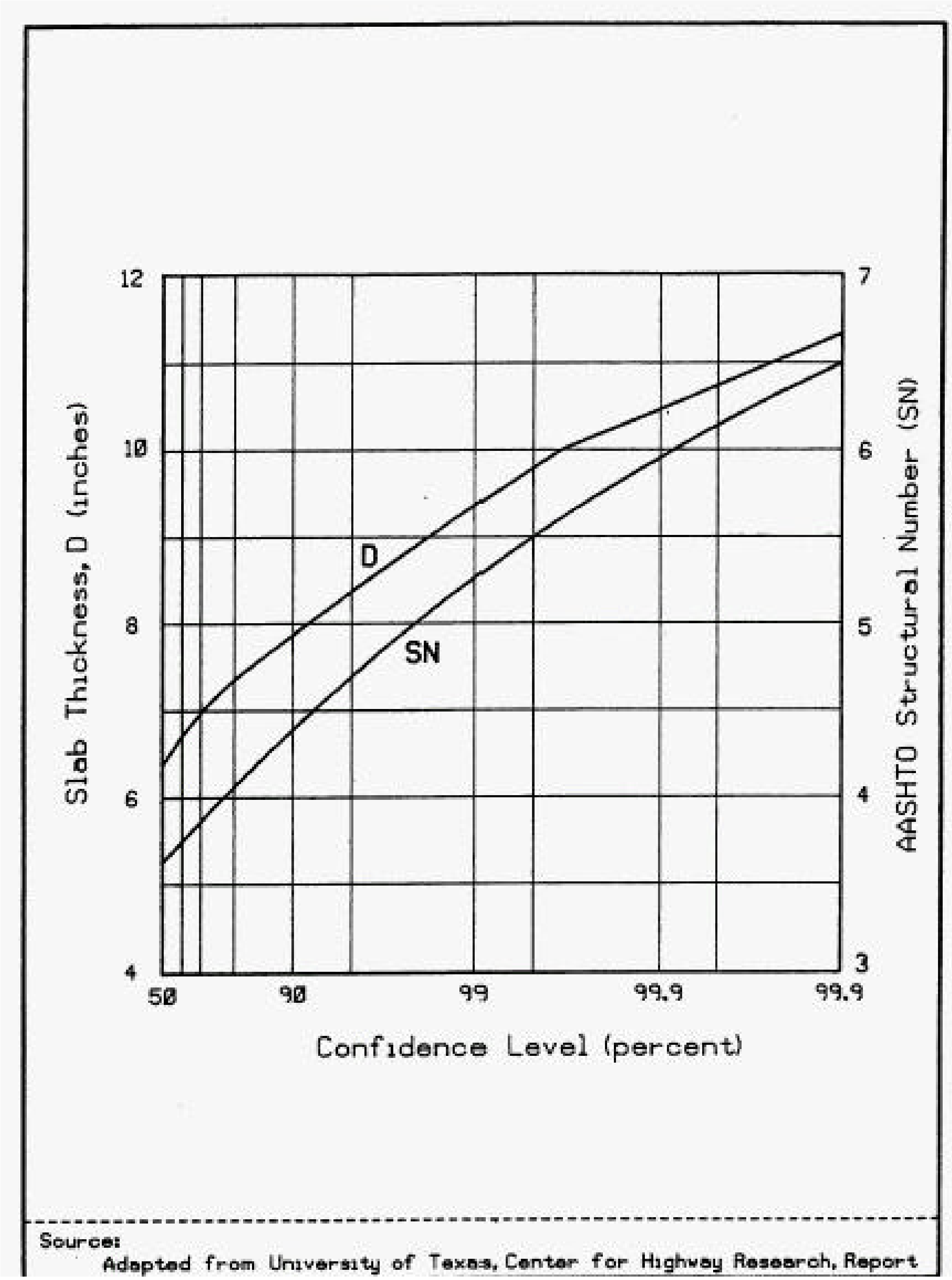


Figure 3-9 Illustration of Linear Maintenance Cost Model used to Estimate Future Maintenance Expenditures for a Given Facility

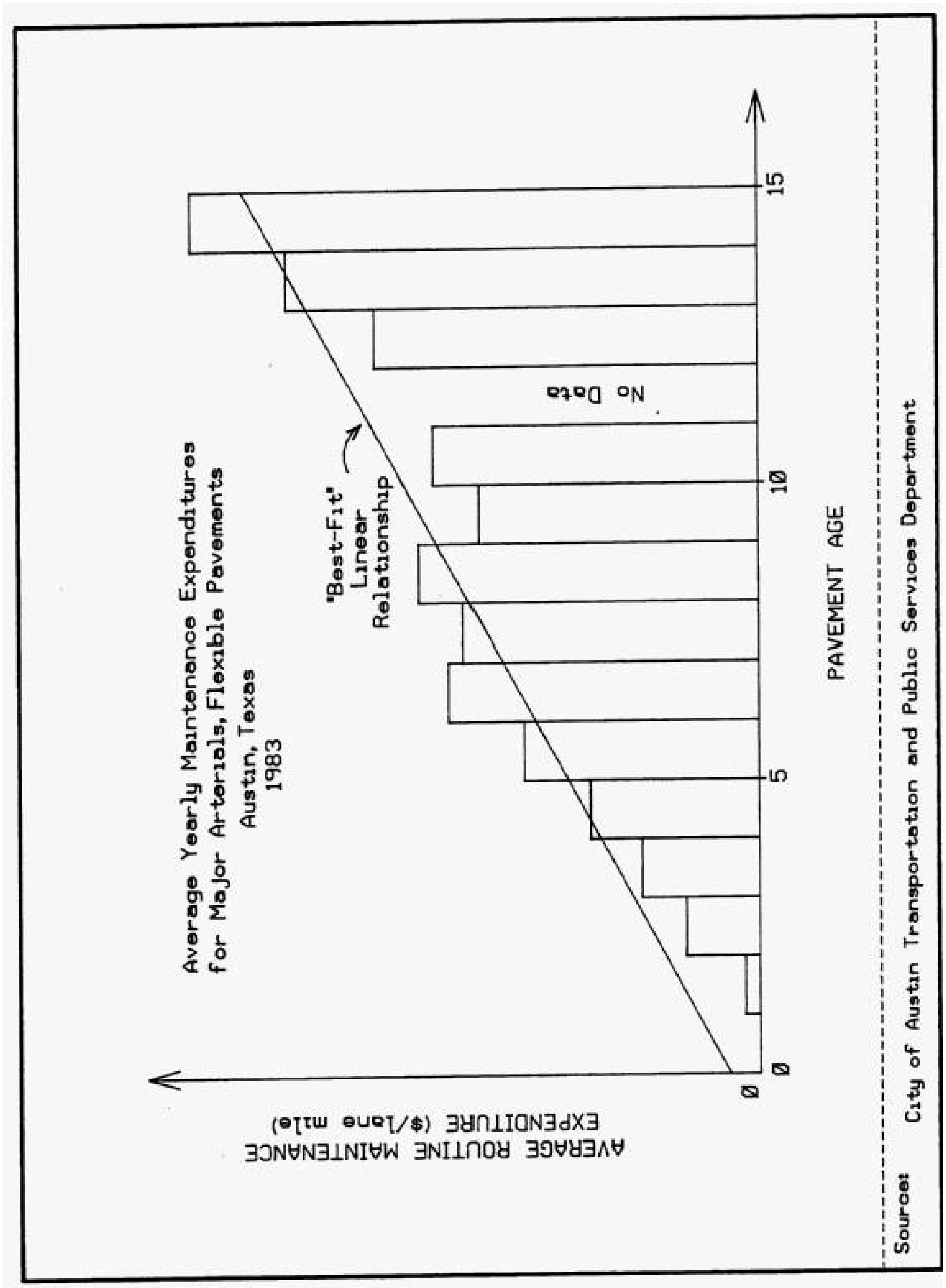


Figure 3-10 Selection Matrix for Base / Subgrade Stabilization

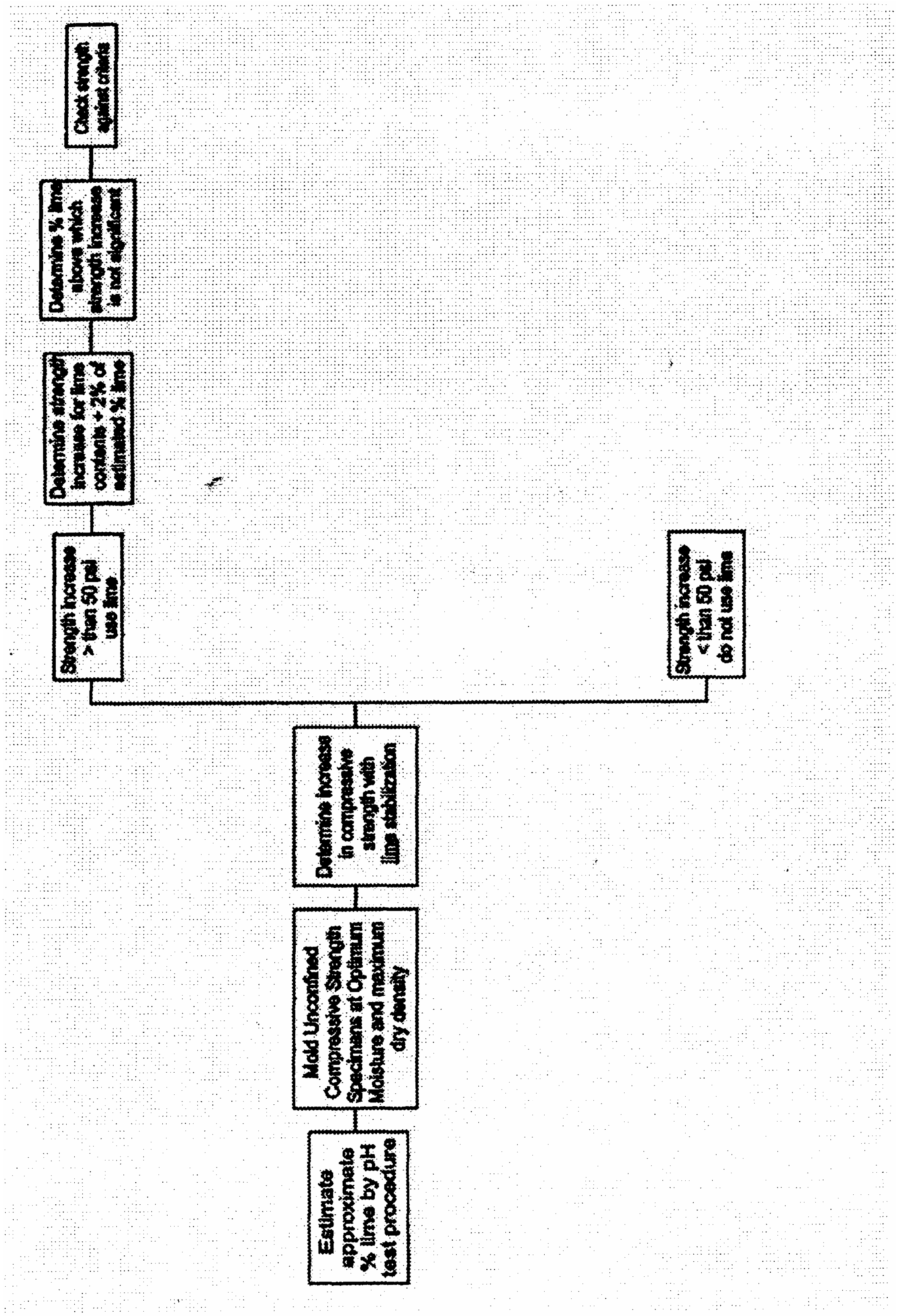


Figure 3-11 Mix Design Subsystem for Lime Stabilization

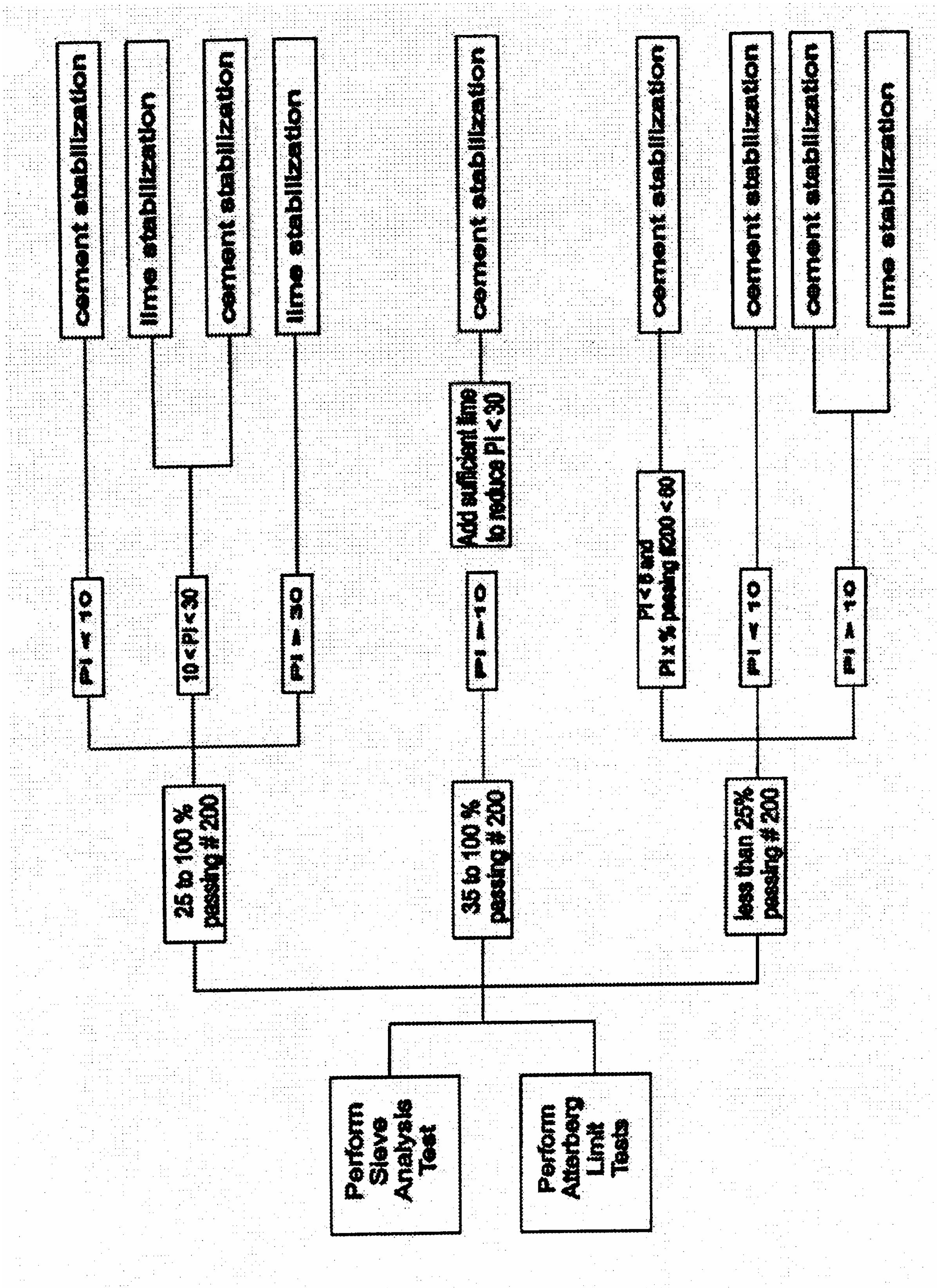


Figure 3-12 Mix Design Subsystem for Cement Stabilization